Experimental studies on hydrodynamic behaviour of flow through a tube with TRIANGULAR WAVY TAPES

A thesis submitted in partial fulfilment of the requirement for the degree of

Bachelor of Technology
in
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Under the Guidance
of

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CERTIFICATE

This is to certify that the thesis entitled, **"Experimental studies on hydrodynamic behaviour of flow through a tube with TRIANGULAR WAVY TAPES "** submitted by **Jasobanta Sandha** in partial fulfilment for the requirements for the award of Bachelor of Technology Degree in Chemical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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CONTENTS

ABSTRACT

The present project work includes the introduction of TWT as inserts as passive augmentation device for tube side liquid flow. The effect of turbulence on friction factor was measured and compared with the values for smooth tube. The effect of baffles was also taken into account and again a comparative study was made on the basis of varying the baffle spacing. All the results and readings were compared with the standard data from the smooth tube. Whenever inserts are used for the heat transfer enhancement, both the heat transfer rate and the pressure drop increase. This increase in pressure drop increases the pumping cost. Thus it is highly essential not to allow the pressure drop to go beyond a specified value while going for heat transfer enhancement techniques using inserts.

Experimental work on hydrodynamic behaviour using TWT is executed. Inserts when placed in the path of the flow of the liquid, both the heat transfer rate and the pressure drop increase, because of increased degree of turbulence created. The present study includes the determination of friction factor for various TWT and its ten modifications. In the beginning, we conducted the experiment without any insert to get the value for plain tube and thereafter the experiment was repeated with TWT without any baffles and with baffles with varying baffle spacing. The results of TWT without any baffles and with baffles with varying baffle spacing have been compared with the values for the smooth tube. It was also observed that with an increase in Reynolds number (Re), the friction factor decreases. The highest value for f_a/f_0 was found to be around 12.

Keywords: Heat Transfer Augmentation, Hydrodynamic Behaviour, Triangular Wavy Tapes (TWT).

LIST OF FIGURES

<u>**LIST OF TABLES**</u>

NOMENCLATURE

A_i	Inner heat transfer area, m^2
d_i	ID of inside tube, m
d_o	OD of inside tube, m
f	Fanning friction factor, Dimensionless
f_a	Experimental friction factor, Dimensionless
f_o	Theoretical friction factor, Dimensionless
g	Acceleration due to gravity, m/s^2
m	Mass flow rate, kg/sec
Re	Reynolds Number, Dimensionless
v	Flow velocity, m/s

Greek letters

Δh	Height difference in manometer, m
ΔP	Pressure difference across heat exchanger, N/m^2
μ	Viscosity of the fluid, N s/m^2
ρ	Density of the fluid, kg/m^3

CHAPTER 1

INTRODUCTION

INTRODUCTION:

Heat transfer is one of the important unit operations in chemical engineering. Heat transfer finds its significant role in steel industry, agricultural product, fertilizer, pharmaceutical, crystallization process, power generation etc. Heat transfer is basically done through heat exchanger. By increasing the thermal performance of heat exchanger we meant making the heat transfer operation more economical and efficient. In order to achieve that, we need to use different heat transfer augmentation techniques.

Several modification and new ideas to enhance the heat transfer led to many technical terms like heat transfer augmentation which is also known as heat transfer intensification or enhancement. Application of augmentation technique increases the heat transfer coefficient but at the same time pressure drop also increases significantly. So, while applying any augmentation technique on heat exchanger, determination of both heat transfer rate and pressure drop has to be done. To get high heat transfer rate in an existing heat exchanger at an economic pumping power many techniques have been applied in recent years and are discussed in the following sections.

For experimental work, TWT and its ten modifications are used. Effect of TWT with baffles with varying baffle spacing have been studied.

CHAPTER 2

LITERATURE REVIEW

2.1 CLASIFICATION OF AUGMENTATION TECHNIQUES:[1,2]

Basically augmentation techniques can be divided into three categories :

1. Passive Techniques

2. Active Techniques

3. Compound Techniques.

1. PASSIVE TECHNIQUES: These methods generally use surface or geometrical modifications to the flow channel by using inserts or additional devices. This method does not involve any external power input. Some examples of passive techniques includes use of inserts, use of rough surfaces etc. Heat transfer augmentation by these techniques can be achieved by using:

- **Treated Surfaces**: They are heat transfer surfaces that have a fine scale altercation to their finish or coating. The altercation could be continuous or is continuous, where the roughness is much smaller than what affects single-phase heat transfer and they are basically used for boiling and condensation duties.
.
- **Rough surfaces**: They are generally surface modifications that promote turbulence in the flow field , primary in single phase flows and do not increase the heat transfer surface area. Their geometric features range from random sand-grain roughness to discrete three dimensional surface protuberances.
- **Extended surfaces**: They refer to as finned surfaces provide an effective heat transfer surface area enlargement. Plain fins have been used routinely in many heat exchangers. The newer developments, however have led to modified finned surfaces that also improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area.
- **Displaced enhancement devices**: They are generally use in confined forced convection and they indirectly improve heat transfer rate at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with

bulk fluid from the core flow.

- **Swirl flow devices**: They produce and superimpose swirl flow or secondary re-circulation on the axial flow in a channel. These include helical strip or cored screw type tube inserts, twisted tapes and They can be used for single phase as well two phase flows.
- **Coiled tubes**: They give more compact heat exchangers. Due to curvature of coils, it produces secondary flow and vortices which promote high heat transfer coefficients in single phase flow.

2. ACTIVE TECHNIQUES: This method involves some external power input for the enhancement of heat transfer. Some examples of active techniques include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc. Heat transfer augmentation by these techniques can be achieved by using:

- **Mechanical Aids**: They are those that stir the fluid by mechanical means or by rotating the surface. The more prominent examples include rotating tube heat exchangers and scraped-surface heat and mass exchangers.
- **Surface vibration**: It has been applied basically, at either low or high frequency, in single phase flows to obtain higher convective heat transfer coefficients.
- **Fluid vibration or fluid pulsation** : Instead of vibrating the surface the same can be achieved by creating pulsations in the fluid itself. This type of vibrational enhancement technique is used in single phase flows.
- **Injection**: This is used in single phase flow. This method injects same or different fluid into the main bulk fluid either through a porous heat transfer interface or upstream of the heat transfer section.
- **Jet impingement:** It involves the direction of heating or cooling fluid perpendicularly or obliquely to the heat transfer surface. Single or multiple jets (in clusters or staged axially along the flow channel) may be used in both single

phase and boiling applications.

3. COMPOUND TECHNIQUES: This technique is a combination of above mentioned two techniques and basically used with a purpose to get the higher performance from the heat exchanger.

CHAPTER 3

PRESENT EXPERIMENTAL WORK

3.1 SPECIFICATIONS OF HEAT EXCHANGER USED:

The present experiments were carried out on a double pipe heat exchanger with the specification listed below:-

Specifications of Heat Exchanger:

Inner pipe ID = 22mm

Inner pipe OD=25mm

Outer pipe ID =53mm

Outer pipe OD =61mm

Material of construction= Copper (Inner tube)

Heat transfer length= 2.43m

Pressure tapping to pressure tapping length = 2.825m

Water at room temperature was permitted to flow through the inner pipe while hot water (set point 60°C) flowed through the annulus side in the counter current direction.

3.2 TYPES OF INSERTS USED

For experimental purpose various types of TWT made from stainless tapes as inserts were used.

1. Triangular Wavy Tapes(TWT)
2. TWT 2A-1
3. TWT 2A-2
4. TWT 2A-3
5. TWT 2A-3 2D-1
6. TWT 2A-3 2D-2
7. TWT 5A-1 2A-2 2D-2
8. TWT 5A-2 2A-1 2D-2
9. TWT 5A-3 2D-2
10. TWT 5A-3 2D-2 BS-4
11. TWT 5A-3 2D-2 BS-2

Fig 3.1a Top view of the wavy plate

Fig 3.1b Isometric view of the wavy plate

Fig 3.1c Design model TWT 2A-1

Fig 3.1d Design model TWT 2A-2

Fig 3.1e Design model TWT 2A-3

Fig 3.1f Design model TWT 2A-3 2D-1

Fig 3.1g Design model TWT 2A-3 2D-2

Fig 3.1h Design model TWT 5A-1 2A-2 2D-2

Fig 3.1i Design model TWT 5A-2 2A-1 2D-2

Fig 3.1j Design model TWT 5A-3 2D-2

Fig 3.2a Design model TWT 5A-3,2D-2,BS-4

Fig 3.2b Design model TWT 5A-3,2D-2,BS-2

3.3 **FABRICATION OF TWT**:

The stainless steel tapes (120 cm length and 12 mm width) were taken. After leaving 2 cm from both ends rest was marked at every 2 cm for making them triangular wavy tapes (TWT). 2 mm holes were drilled at both ends of each tape so that they can be connected to each other by using screws to get the total length.

3.4 **EXPERIMENTAL SETUP:**

Fig.3.3 shows the schematic diagram of the experimental setup. It is primarily a double pipe heat exchanger consisting of an inner pipe of ID 22mm and OD 25mm, and an outer pipe of ID 53mm and OD 61 mm. The apparatus is also provided with two rotameters for continuously measuring and maintaining the particular flow rate . There are two rotameters 1 for hot water flow measuring and another one for the cold water. There is a bore-well has an inbuilt submersible pump for providing cold water. There is another tank of capacity 500 litre which has an inbuilt heater and pump for providing hot water of a particular temperature at a particular flow rate. This apparatus is also equipped with the RTD meter. They have four different sensors situated at different locations to give four temperature T1, T2, T3, T4.

Hot water flow rate was kept constant at 1000 kg/hr during the experiment.

There is a U-Tube manometer for the pressure drop measurement it consist of two limbs well connected with the two points in the inner pipe. Carbon Tetra Chloride (CCl_4) was taken as manometric fluid inside the U-Tube manometer

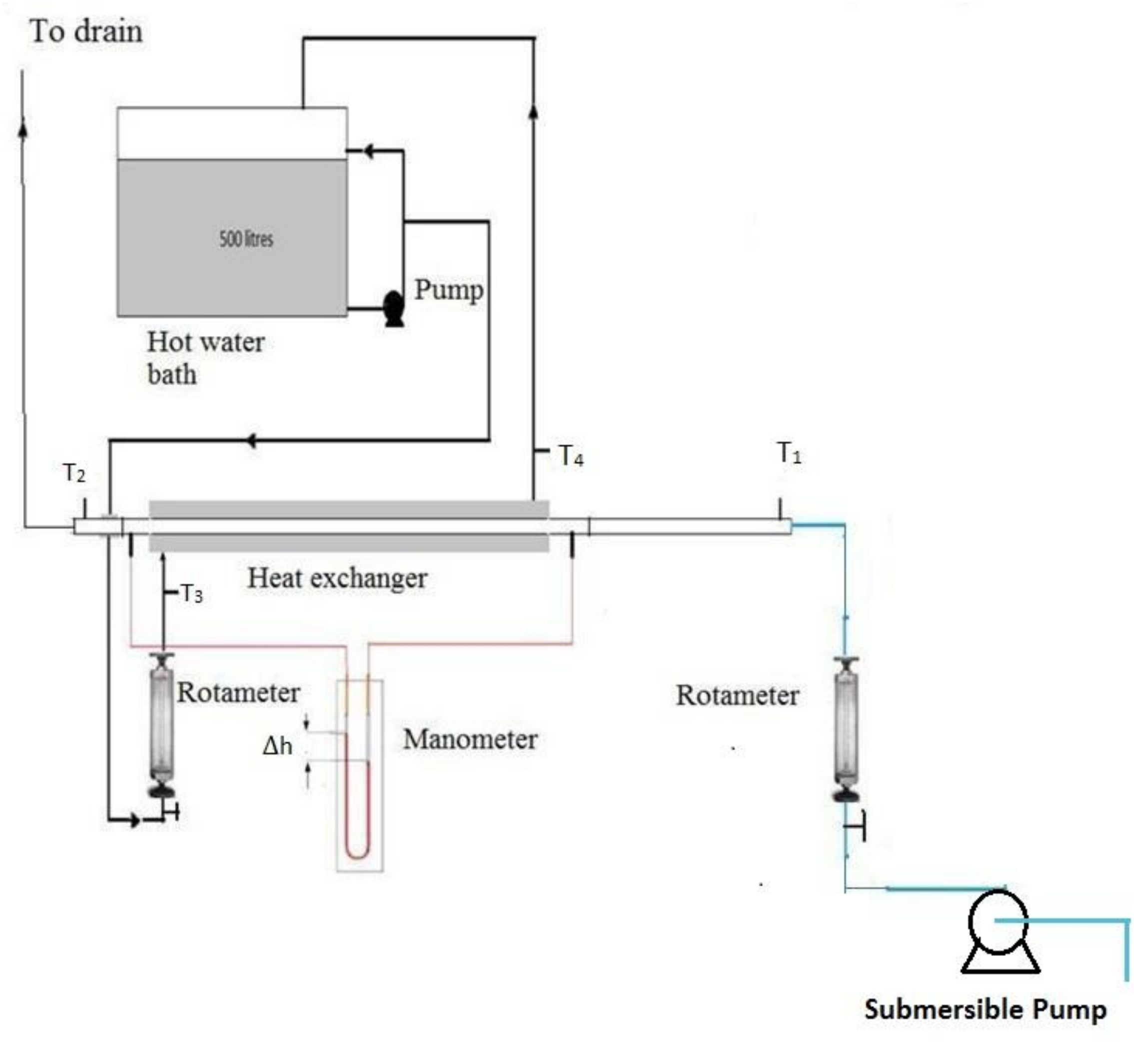

Fig 3.3 Schematic Diagram for the experimental setup

Fig 3.4 Photograph of the experimental setup

3.5 EXPERIMENTAL PROCEDURE:

1. All the RTD and Rotameter were calibrated first.

i. For rotameter calibration, we collected water in the bucket and simultaneously time was noted and then weight was taken. Thus mass flow rate was calculated.

ii. We repeated this for three times for each particular reading and then took average of all. The readings are given in A.1.1.

iii. For RTD calibration, all the RTDs were simultaneously dipped in the same water bucket and readings were noted. T1 was made reference & corrections were made to other RTDs values (i.e. T2-T4) accordingly.

2. For friction factor determination:

Pressure drop is calculated for each flow rate with the help of manometer at room temperature.

a. The U-tube manometer used carbon tetrachloride as the manometric fluid.

b. Air bubbles were removed from the manometer so that the liquid levels in both limbs was equal at zero flow rate.

c. Water at room temperature is allowed to flow through the inner pipe of the heat exchanger.

d. The manometer reading is noted.

e. Standardization of smooth tube:-

Before starting the experimental study on heat transfer augmentation using inserts, standardization of the smooth tube (without insert) has to be done so that the % difference between the theoretical frictional factor value and the experimental value can be found.(Table no-A.2.1)

3.6 STANDARD EQUATIONS USED:

I. Friction factor (f_o) calculations*:*

a. For Re< 2100

$$f = \frac{16}{Re}$$

b. For Re>2100

Colburn's Equation:

$$f = \frac{0.046}{Re^{0.2}}$$

CHAPTER 4

SAMPLE CALCULATIONS

4.1 ROTAMETER CALIBRATION:

For 600 Kph (Table No. A1.1)

Observation No.1:

Weight of water collected=1.44 kg

Time=8.27sec

m1=0.174 kg/sec

Observation No.2:

Weight of water collected=1.41 kg

Time=8.61 sec

m2=0.163 kg/sec

Observation No.3:

Weight of water collected=1.5 kg

Time=8.56 sec

m3=0.175 kg/sec

$m = \frac{m1+m2+m3}{3} = \frac{0.174 + 0.163 + 0.175}{3}$ = 0.170Kg/sec

4.2 PRESSURE DROP & FRICTION FACTOR CALULATIONS:

For smooth tube (Table No A.2.1)

m=0.170 kg/sec

Experimental friction factor:

$A = \frac{\pi d_i^2}{4} = \frac{3.14*0.022^2}{4} = 3.8 * 10^{-4}$

$\upsilon = \frac{m}{A*\rho_w} = \frac{0.170}{3.8*10^{-4}*10^3}$ =0.44 m/sec

$\Delta P = (\rho_{ccl4} - \rho_w) * g * \Delta h = (1603 - 1000) * 9.8 * 5.5 * 10^{-2}$=*325.01*

$f_{exp} = \frac{\Delta P * d_i}{2*\rho_w*L*\upsilon^2} = \frac{325.01*0.022}{2*1000*2.83*(0.44)^2} = 6.52 * 10^{-3}$

μ = 0.85 cP

Theoritical friction factor:

$Re = \frac{4 \times m}{(\pi \times d_i \times \mu)} = \frac{4\times0.170}{3.14\times0.022\times0.00085}$ =11724.13

f_{theo} = 0.046 × $Re^{-0.2}$ =0.046× $(11724.13)^{-0.2}$ =7.062× 10^{-3}

% difference=$\frac{f_{theo} - f_{exp}}{f_{theo}} \times 100 = \frac{7.062\times10^{-3} - 6.52\times10^{-3}}{7.062\times10^{-3}} \times 100 = 7.64$

CHAPTER 5

RESULTS & DISCUSSION

RESULTS & DISCUSSION

5.1 FRICTION FACTOR RESULTS:

All the graphs (Fig.5.1-5.3) below have plotted in log-log scale.

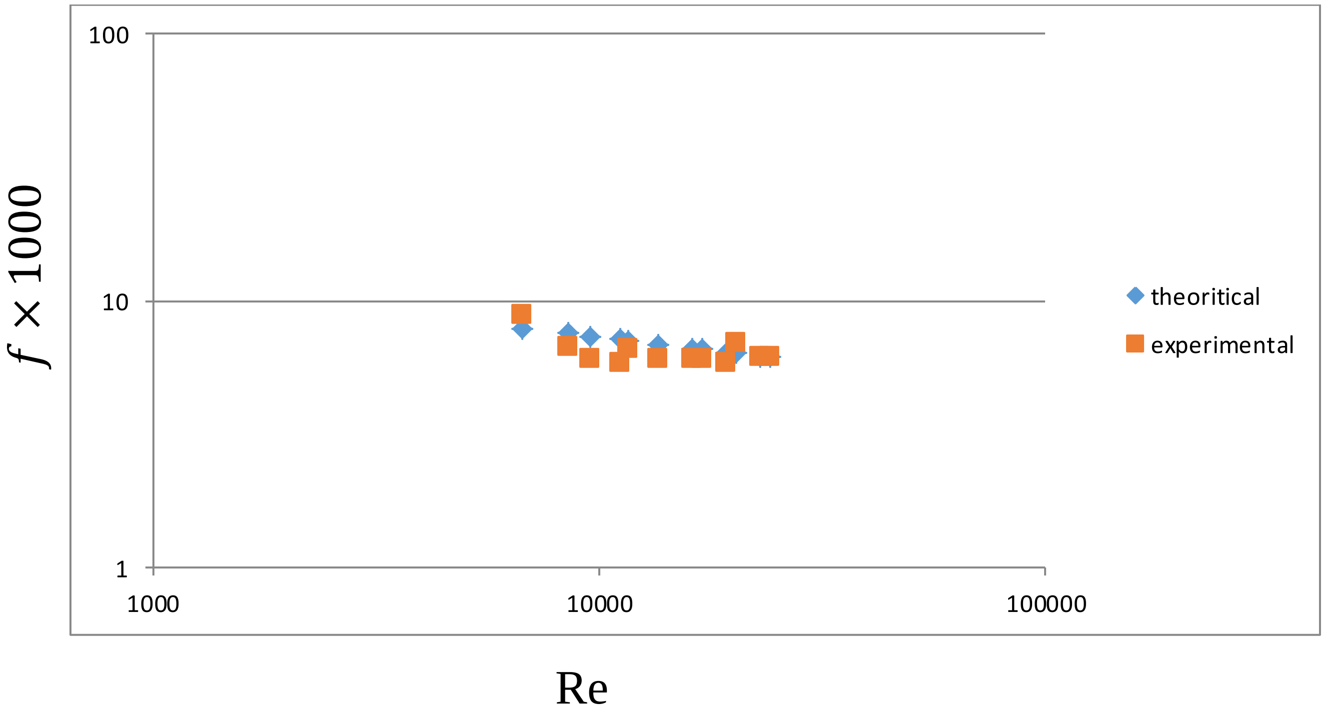

Fig 5.1 Friction Factor vs. Reynolds number for Smooth Tube.

Fig. 5.2 represents the variation of friction factor with Reynolds no. for TWT without baffle, with baffles. As the number of baffles increases, the friction factor also increases. So for TWT 5A-3 2D-2 BS-2 friction factor is highest. Inserts with baffles are giving high friction factor because of increase in the degree of turbulence.

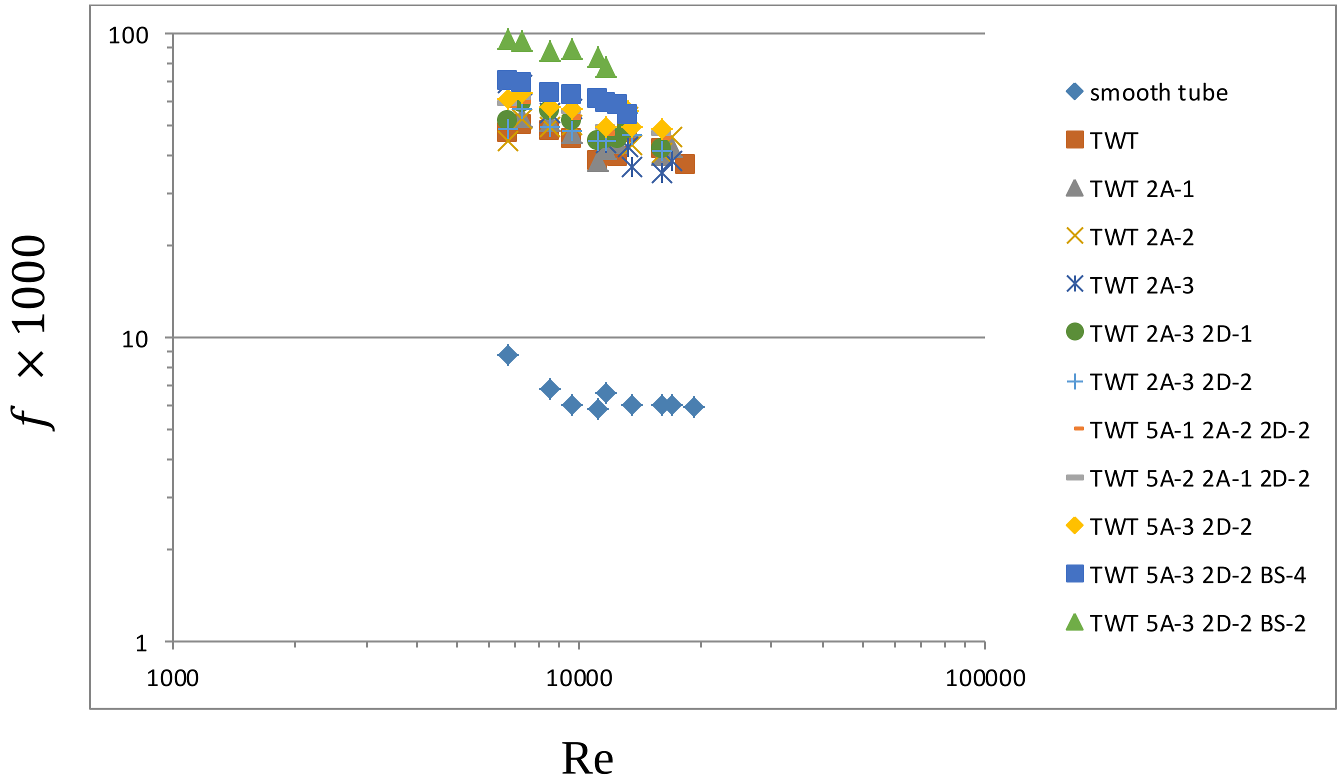

Fig 5.2 Friction factor vs. Reynolds number for Smooth tube, inserts with baffles and without baffles.

Fig 5.3 shows the variation of f_a/f_o with Reynolds number for TWT inserts with and without baffles. f_a/f_o is found to be highest for TWT 5A-3 2D-2 BS-2. f_a/f_o is lowest in case of TWT inserts without any baffles. f_a/f_o is large for TWT inserts with baffles.

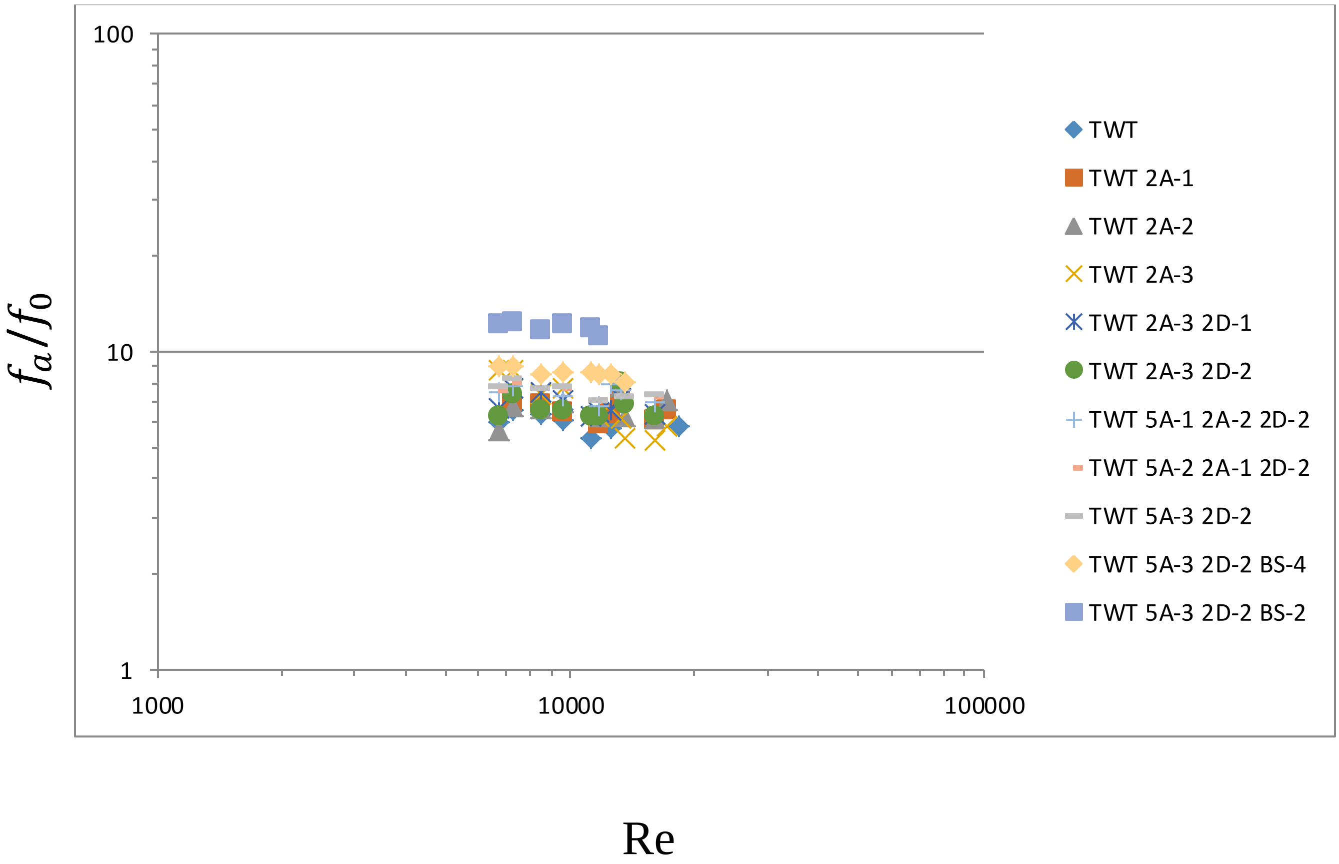

Fig 5.3 f_a/f_o vs. Reynolds Number for TWT inserts with and without baffles.

CHAPTER 6

CONCLUSIONS

1. Inserts with baffles shows greater friction factor than the value we get for inserts without baffles, because of increased degree of turbulence created.
2. With the decrease in baffle spacing, the friction factor increases.
3. It is observed that with an increase in the Reynolds number (Re), the friction factor decreases.
4. In general the friction factor increases as the number and size of the holes are increased from tape Sl. No. 1to 9.
5. The ranges of the increase in friction factors for the different tapes are as given below.

Sl. No.	Insert	Range of f_a/f_o
1	TWT	5.33-6.87
2	TWT 2A-1	5.88-7.15
3	TWT 2A-2	5.64-7.76
4	TWT 2A-3	5.23-8.72
5	TWT 2A-3 2D-1	6.19-7.67
6	TWT 2A-3 2D-2	6.19-7.98
7	TWT 5A-1 2A-2 2D-2	6.72-7.71
8	TWT 5A-2 2A-1 2D-2	7.01-8.18
9	TWT 5A-3 2D-2	7.01-8.24
10	TWT 5A-3 2D-2 BS-4	7.93-8.90
11	TWT 5A-3 2D-2 BS-2	11.08-12.22

CHAPTER 7

SCOPE FOR FUTURE WORK

Further modification can be done using this study as base. Some of the possibilities are mentioned below:

1. Distance between two consecutive baffles (baffle spacing) can be varied and their effect on friction factor can easily be noted down.
2. Pressure drop is a big loss of this modification so studies can be made to minimize the pressure drop.
3. Design of baffles are also a subject to affect the friction factor.
4. The same experiment can also be tested with cooling operations.

REFERENCES:

(1) Bergles, A.E. "Techniques to augment heat transfer." In Handbook of Heat Transfer Applications (Ed.W.M. Rosenhow), 1985, Ch.3 (McGraw-Hill, NewYork).

(2) Saha, S. K. and Dutta, A. "Thermo-hydraulic study of laminar swirl flow through a circular tube fitted with twisted tapes." Trans. ASME, J. Heat Transfer, 2001, 123, 417–421.

(3) Manglik, R. M. and Bergles, A. E. "Heat transfer and pressure drop correlations for twisted tape insert in isothermal tubes." Part 1: laminar flows. Trans. ASME, J. Heat Transfer, 1993, 116, 881–889.

(4) AGARWAL, S. K. and RAJA RAO, M. "Heat transfer augmentation for the flow of a viscous liquid in circular tubes using twisted tape inserts." Int. J. Heat Mass Tranffer. 1996, 39, 3547-3557,

(5) Al-Fahed, S., Chamra, L. M., Chakroun. W. Pressure drop and heat transfer comparison for both micro-fin tube and twisted-tape inserts in laminar flow. Experimental Thermal and Fluid Sci., Vol. 18 (1999), pp. 323–333

(6) Sivashanmugam, P. and Suresh, S. "Experimental studies on heat transfer and friction factor characteristics of turbulent flow through a circular tube fitted with regularly spaced helical screw tape inserts", Advances in Energy Research, 2006, 468-473.

APPENDIX

A.1. CALIBRATION

A.1.1 ROTAMETER CALIBRATION

	Observation 1			Observation 2			Observation 3			
Rotameter reading (kg/hr)	**Wt (kg)**	**Time (sec)**	**m (kg/sec)**	**Wt (kg)**	**Time (sec)**	**m (kg/sec)**	**Wt (kg)**	**Time (sec)**	**m (kg/sec)**	**Average m**
350	0.96	9.97	0.096	0.81	8.19	0.098	0.85	8.46	0.100	0.098
450	1.11	8.96	0.123	1.19	9.31	0.127	1.07	8.76	0.122	0.124
500	1.29	9.33	0.138	1.36	9.21	0.147	1.15	8.41	0.136	0.140
550	1.46	8.90	0.164	1.49	9.03	0.165	1.32	8.14	0.162	0.163
600	1.44	8.27	0.174	1.41	8.61	0.163	1.5	8.56	0.175	0.170
700	1.62	8.18	0.198	2.00	9.86	0.202	1.72	8.80	0.195	0.198
800	2.21	9.15	0.241	1.97	8.24	0.239	1.85	8.15	0.226	0.235
900	2.26	8.90	0.253	2.05	8.00	0.256	2.1	8.72	0.240	0.249
1000	2.46	8.73	0.281	2.58	8.95	0.288	2.45	8.78	0.279	0.282
1100	2.27	7.86	0.288	2.87	10.03	0.286	2.67	8.44	0.316	0.296
1200	2.39	7.50	0.318	2.72	7.99	0.340	2.81	8.11	0.346	0.334
1300	2.74	7.58	0.361	2.36	6.76	0.349	2.5	7.16	0.349	0.353

A.1.2 RTD CALIBRATION

Sl.no	Temperature readings			
	T1	**T2**	**T3**	**T4**
1	14.7	14.6	15.0	15.0
2	15.2	15.0	15.3	15.5
3	15.2	15.0	15.3	15.5
correction	0	+0.2	-0.1	-0.3

A.2. FRICTION FACTOR RESULTS:

A.2.1 STANDARDISATION OF SMOOTH TUBE (f vs. Re)

m(kg/sec)	$\Delta H(cm)$	**Re**	$\Delta P(N/m^2)$	**f_a*1000**	**f_o*1000**	**%diff.**
0.098	2.4	6758	141.82	8.81	7.88	-13.07
0.124	3.0	8551	177.28	6.72	7.52	10.63
0.140	3.4	9655	200.91	6.02	7.34	17.98
0.163	4.5	11241	265.92	5.85	7.12	17.83
0.170	5.5	11724	325.01	6.52	7.06	7.64
0.198	7.1	13655	419.56	6.03	6.85	11.97
0.235	9.7	16206	573.21	5.98	6.61	9.53
0.249	11.1	17172	655.94	6.03	6.54	7.79
0.282	14	19448	827.31	5.87	6.38	7.99
0.296	18	20413	1122.78	6.91	6.32	-9.33
0.334	20.2	23034	1193.69	6.12	6.16	0.64
0.353	22.8	24344	1347.34	6.18	6.10	-1.31

A.2.2 FRICTION FACTOR vs. Re FOR TWT

m(kg/sec)	$\Delta H (cm)$	Re	$\Delta P (N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	12.8	6758	756.4	47.03	7.88	5.96
0.106	16	7310	945.5	50.41	7.76	6.49
0.124	21.2	8551	1252.7	47.53	7.52	6.32
0.140	25.2	9655	1489.1	44.66	7.34	6.08
0.163	29.2	11241	1725.5	38.02	7.12	5.33
0.171	33	11793	1950.1	43.53	7.05	6.17
0.183	39.6	12620	2340.1	39.47	6.95	5.67
0.194	53.5	13379	3161.5	47.24	6.87	6.87
0.235	67.2	16206	3971.1	41.47	6.61	6.27
0.268	79.3	18482	4686.1	37.17	6.44	5.77

A.2.3 FRICTION FACTOR vs. Re FOR TWT 2A-1

m(kg/sec)	$\Delta H (cm)$	Re	$\Delta P (N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.106	17	7310	1004.5	53.53	7.76	6.89
0.124	22.9	8551	1353.2	51.37	7.52	6.83
0.140	26.6	9655	1571.9	47.14	7.34	6.42
0.171	36.6	11793	2162.8	41.48	7.05	5.88
0.183	44.1	12620	2606.04	43.96	6.95	6.32
0.194	55.7	13379	3291.53	49.18	6.87	7.15
0.235	64.9	16206	3835.20	40.06	6.61	6.06
0.235	70	16206	4136.5	43.20	6.61	6.53
0.249	78.3	17172	4627.06	42.56	6.54	6.50

A.2.4 FRICTION FACTOR vs. Re FOR TWT 2A-2

m(kg/sec)	$\Delta H (cm)$	Re	$\Delta P (N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	12.1	6758	715.03	44.46	7.88	5.64
0.106	16.6	7310	980.96	52.27	7.76	6.73
0.124	22.1	8551	1305.97	49.55	7.52	6.58
0.140	28.4	9655	1678.26	50.33	7.34	6.85
0.171	38.5	11793	2275.11	43.66	7.05	6.19
0.198	50.4	13655	2978.33	42.81	6.85	6.24
0.194	60.4	13379	3569.27	53.33	6.87	7.76
0.235	65.6	16206	3876.56	40.49	6.61	6.12
0.235	71.8	16206	4242.94	44.31	6.61	6.70
0.249	84.1	17172	4969.80	45.71	6.54	6.98

A.2.5 FRICTION FACTOR vs. Re FOR TWT 2A-3

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	18.6	6758	1099.1	68.35	7.88	8.67
0.106	21.5	7310	1270.5	67.73	7.76	8.72
0.124	24.3	8551	1435.9	54.48	7.52	7.24
0.140	31.8	9655	1879.1	56.35	7.34	7.67
0.171	38.7	11793	2286.9	43.89	7.05	6.22
0.198	42.7	13655	2523.3	36.27	6.85	5.29
0.194	47.7	13379	2818.7	42.12	6.87	6.13
0.235	56.1	16206	3315.1	34.62	6.61	5.23
0.249	70.1	17172	4142.4	38.10	6.54	5.82

A.2.6 FRICTION FACTOR vs. Re FOR TWT 2A-3 2D-1

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	14.1	6758	833.2	51.81	7.88	6.57
0.106	18.9	7310	1116.8	59.52	7.76	7.67
0.124	24.7	8551	1459.6	55.40	7.52	7.36
0.140	28.9	9655	1707.8	51.21	7.34	6.97
0.163	33.9	11241	2003.2	44.13	7.12	6.19
0.171	39.6	11793	2340.1	44.91	7.05	6.37
0.183	45.4	12620	2682.8	45.25	6.95	6.51
0.194	54.8	13379	3238.3	48.39	6.87	7.04
0.235	67.9	16206	4012.4	41.91	6.61	6.34
0.235	74.6	16206	4408.4	46.04	6.61	6.96

A.2.7 FRICTION FACTOR vs. Re FOR TWT 2A-3 2D-2

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	13.3	6758	785.9	48.84	7.88	6.19
0.106	17.9	7310	1057.7	56.37	7.76	7.26
0.124	21.9	8551	1294.1	49.12	7.52	6.53
0.140	26.8	9655	1583.7	47.49	7.34	6.47
0.163	33.9	11241	2003.2	44.13	7.12	6.19
0.171	38.8	11793	2292.8	44.00	7.05	6.24
0.198	54.5	13655	3220.6	46.29	6.85	6.75
0.194	62.1	13379	3669.7	54.83	6.87	7.98
0.235	66.7	16206	3941.5	41.17	6.61	6.22
0.235	75.9	16206	4485.2	46.85	6.61	7.08

A.2.8 FRICTION FACTOR vs. Re FOR TWT 5A-1 2A-2 2D-2

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	15.8	6758	933.6	58.03	7.88	7.36
0.106	19	7310	1122.7	59.83	7.76	7.71
0.140	29.8	9655	1761	52.81	7.34	7.19
0.171	41.8	11793	2470.1	47.41	7.05	6.72
0.183	54.9	12620	3244.2	54.72	6.95	7.81
0.194	58.5	13379	3456.9	51.65	6.87	7.51
0.235	73.8	16206	4361.1	45.55	6.61	6.89
0.235	77.4	16206	4573.8	47.77	6.61	7.22

A.2.9 FRICTION FACTOR vs. Re FOR TWT 5A-2 2A-1 2D-2

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	16.2	6758	957.3	59.53	7.88	7.55
0.106	19.5	7310	1152.3	61.41	7.76	7.91
0.140	31.6	9655	1867.3	55.98	7.34	7.62
0.171	43.6	11793	2576.4	49.45	7.05	7.01
0.183	57.1	12620	3374.2	56.92	6.95	8.18
0.194	62.3	13379	3681.5	55.01	6.87	8.00
0.235	76.7	16206	4532.5	47.33	6.61	7.16
0.235	77.1	16206	4556.1	47.59	6.61	7.19

A.3.0 FRICTION FACTOR vs. Re FOR TWT 5A-3 2D-2

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	16.6	6758	980.96	61	7.88	7.74
0.106	20.3	7310	1199.6	63.95	7.76	8.24
0.124	25.5	8551	1506.8	57.17	7.52	7.60
0.140	32	9655	1891	56.71	7.34	7.72
0.171	43.6	11793	2576.4	49.45	7.05	7.01
0.198	58.1	13655	3433.3	49.35	6.85	7.20
0.194	63.1	13379	3728.8	55.72	6.87	8.11
0.235	78.1	16206	4615.2	48.20	6.61	7.29

A.3.1 FRICTION FACTOR vs. Re FOR TWT 5A-3 2D-2 BS-4

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	19.1	6758	1128.6	70.16	7.88	8.90
0.106	21.9	7310	1294.1	68.99	7.76	8.89
0.124	28.3	8551	1672.3	63.47	7.52	8.44
0.140	35.5	9655	2097.8	62.91	7.34	8.57
0.163	46.7	11241	2759.6	60.80	7.12	8.53
0.171	52.3	11793	3090.6	59.32	7.05	8.41
0.183	58.7	12620	3468.8	58.51	6.95	8.41
0.198	64	13379	3782	54.36	6.85	7.93

A.3.2 FRICTION FACTOR vs. Re FOR TWT 5A-3 2D-2 BS-2

m(kg/sec)	$\Delta H(cm)$	Re	$\Delta P(N/m^2)$	f_a*1000	f_o*1000	f_a/f_o
0.098	26	6758	1536.4	95.54	7.88	12.12
0.106	30.1	7310	1778.7	94.83	7.76	12.22
0.124	39.1	8551	2310.5	87.70	7.52	11.66
0.140	50	9655	2954.7	88.61	7.34	12.07
0.163	64	11241	3782	83.33	7.12	11.70
0.171	68.9	11793	4071.5	78.14	7.05	11.08